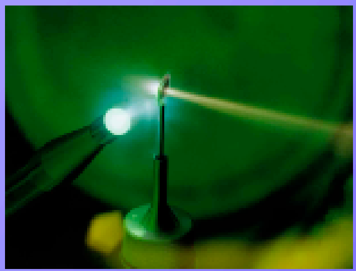
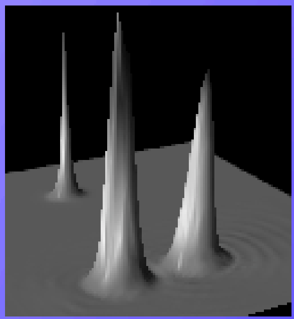
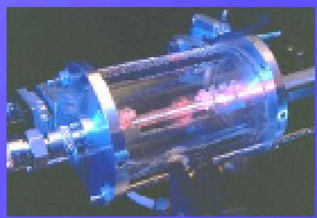
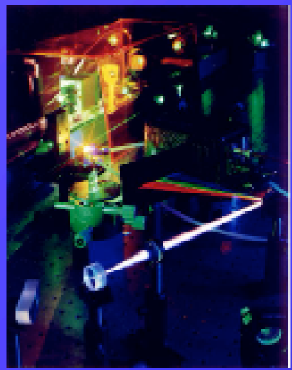
# High Energy Density Physics with Ultrafast, Ultraintense Lasers

Update from the Ultrafast, Ultraintense Laser Working group

May 26, 2004

# The principal thrusts isolated by the UUL working group

1. Intense laser excitation of many particle systems at the relativistic extreme

2. Control of intrinsic and strong-field dynamics on attosecond time-scales

3. Ultrafast, high peak power x-ray generation

4. Compact high energy electron and proton acceleration

5. Inertial fusion energy fast ignition

5b. Isochoric heating of solids to high temperature (Gbar at solid density)

# We have formulated six compelling intellectual questions facing the field of ultrafast ultraintense laser science

- How do many-body systems evolve in a light field under extreme relativistic conditions where an electron is accelerated to relativistic energies and particle production becomes possible in one optical cycle?

- Can physical and chemical processes be controlled with man-made light pulses that possess both the intrinsic time- (attoseconds, 1 as = $10^{-18}$ s) and length- (x-rays, 1 Å) scales of all matter?

- Can intense, ultra-fast x-rays become a routine tool for imaging the structure and motion of “single” complex bio-molecules that are the constituents of all living things?

- Can nonlinear optics be applied as a powerful, routine probe of matter in the XUV/x-ray regime?

- Can ultra-intense ultra-short pulse lasers be used to drive table-top GeV class electron and or proton/ion accelerators?

- Is it possible to make controlled nuclear fusion useful and efficient by heating plasmas with an intense, short pulse laser ?

# We are drafting an introductory section to address the broad community needs in UUL science

5.0 Summary and community organization

I. Facility needs of the UUL community
- Range of short pulse lasers from 1 mJ to 1 kJ

II. Statement about the change in mode from single PI to mid-scale efforts –
Need for single shot facilities and high average power facilities
These facilities can service multiple scientific thrusts

III. Computational high intensity laser science – massively parallel processing capability needed,
Support needed for all thrust areas
Access to computing facilities needed

IV. New technological approaches needed to push the frontier in peak power, average power and focused intensity well beyond 1 PW. Some novel approaches are being pursued at smaller scale.

V. Opportunities can be best exploited if the agencies consider using facilities already under
development by NNSA, DOE SC and NSF.
Use by the network of single agency supported facilities
Describe network. Two modes: (1) those that use existing large facilities (2) those based
on smaller scale in house facilities

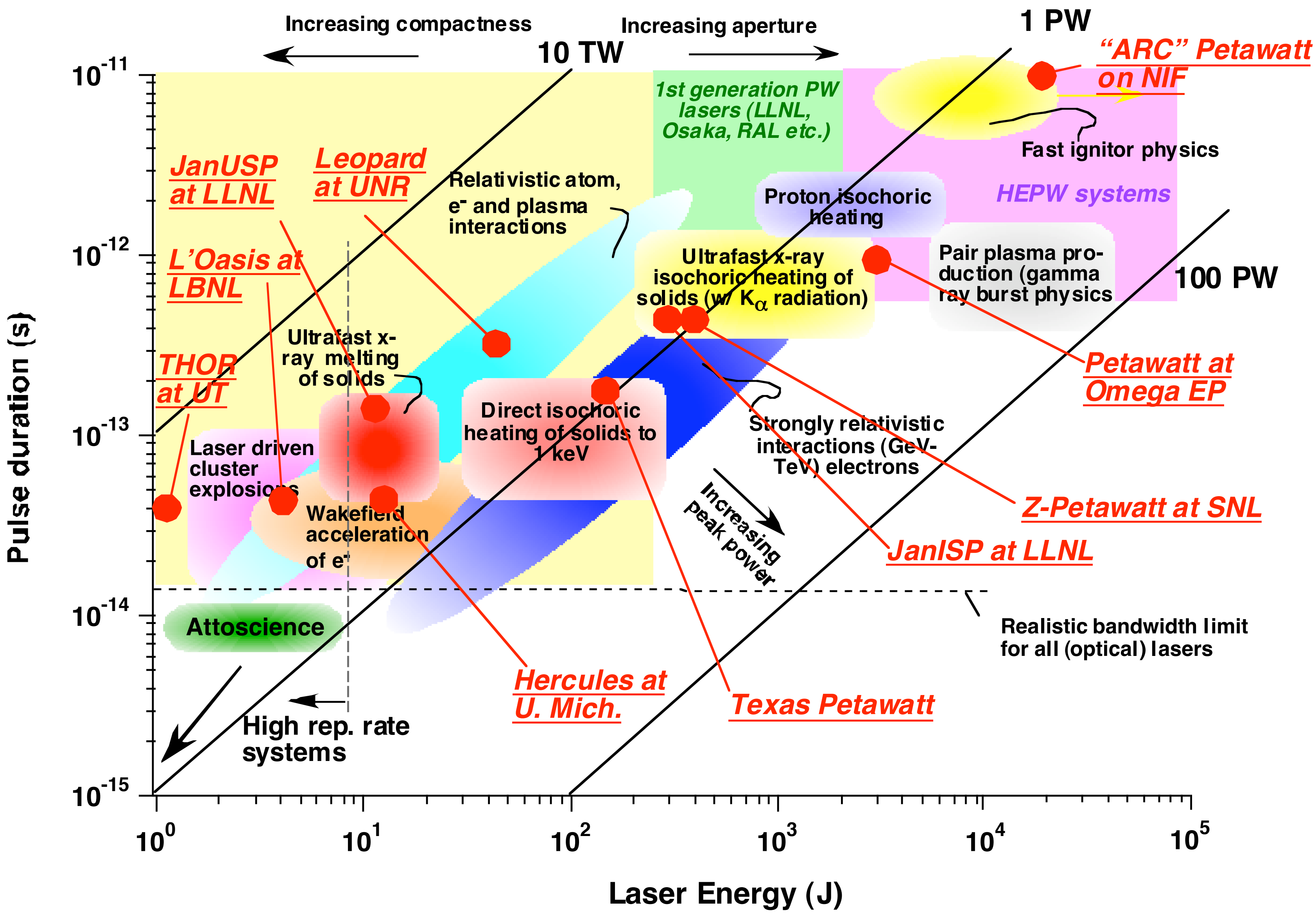
VI. Establishing collaborative scientific thrusts

VII. Facility needs of this community

# The set of UUL research thrusts will greatly benefit from a diverse range of short pulse lasers

| | Relativistic plasmas | Attoscience | Ultrafast x-rays | Particle Acceleration | Fast Ignition | Warm/Hot dense matter | $ |
|---|---|---|---|---|---|---|---|
| kW class kHz fs lasers<br>~1-10 mJ/pulse | | XX | X | | | | ~$2M |
| Table top multi-TW lasers<br>~1 J/pulse | X | | X | X | | X | ~$2M |
| 100 TW class rep rated lasers<br>~3-10 J/pulse | X | | X | XX | | X | ~$5M |
| Compact fs PW<br>~30 J J/30 fs | XX | X | X | X | | X | ~$5M |
| Single shot PW<br>~100J – 1 kJ | X | | X | X | X | XX | ~$10-30M |
| High energy PW lasers at implosion facilities<br>~1-10 kJ | X | | | X | XX | X | ~$50-100M |
| High energy SPL(>1 J) SPL at accelerator based light sources<br>~1 – 100 J | | | XX | | | X | ~$2-5M |

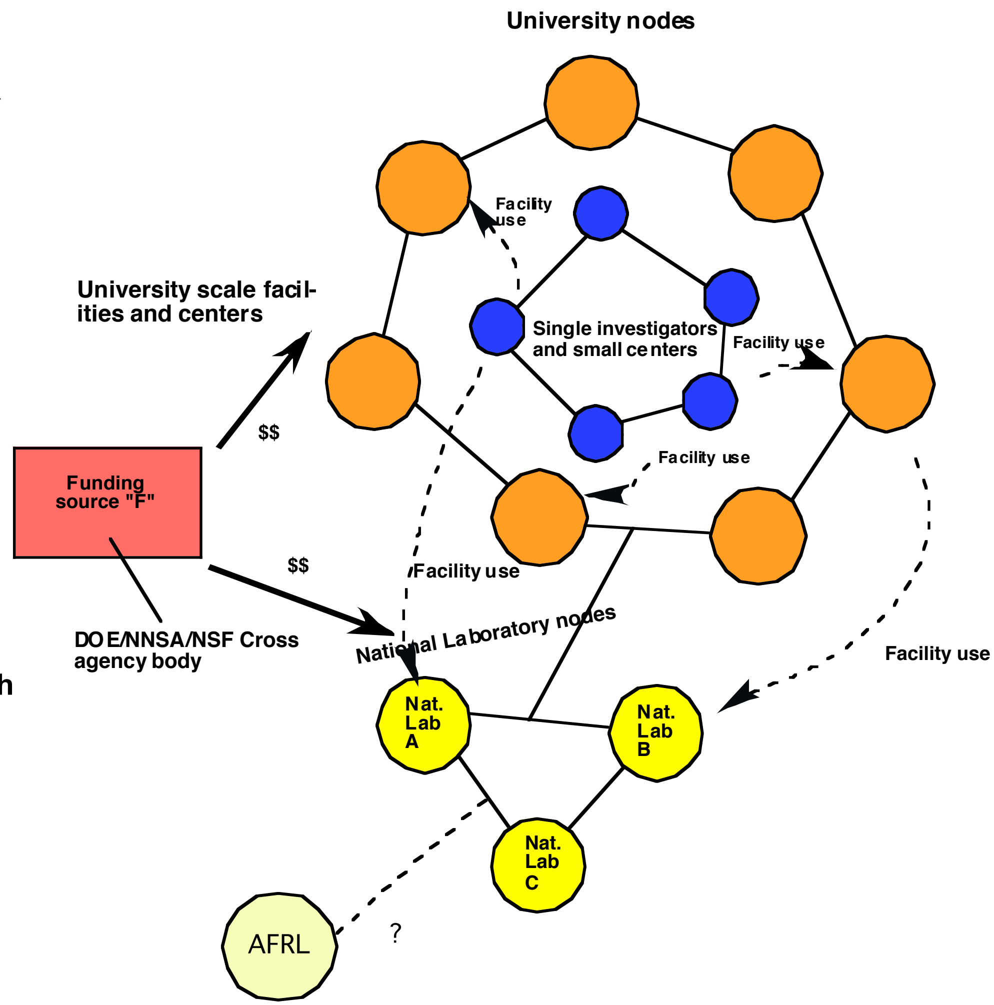
# A UUL phase space plot indicates the diversity of systems currently under development



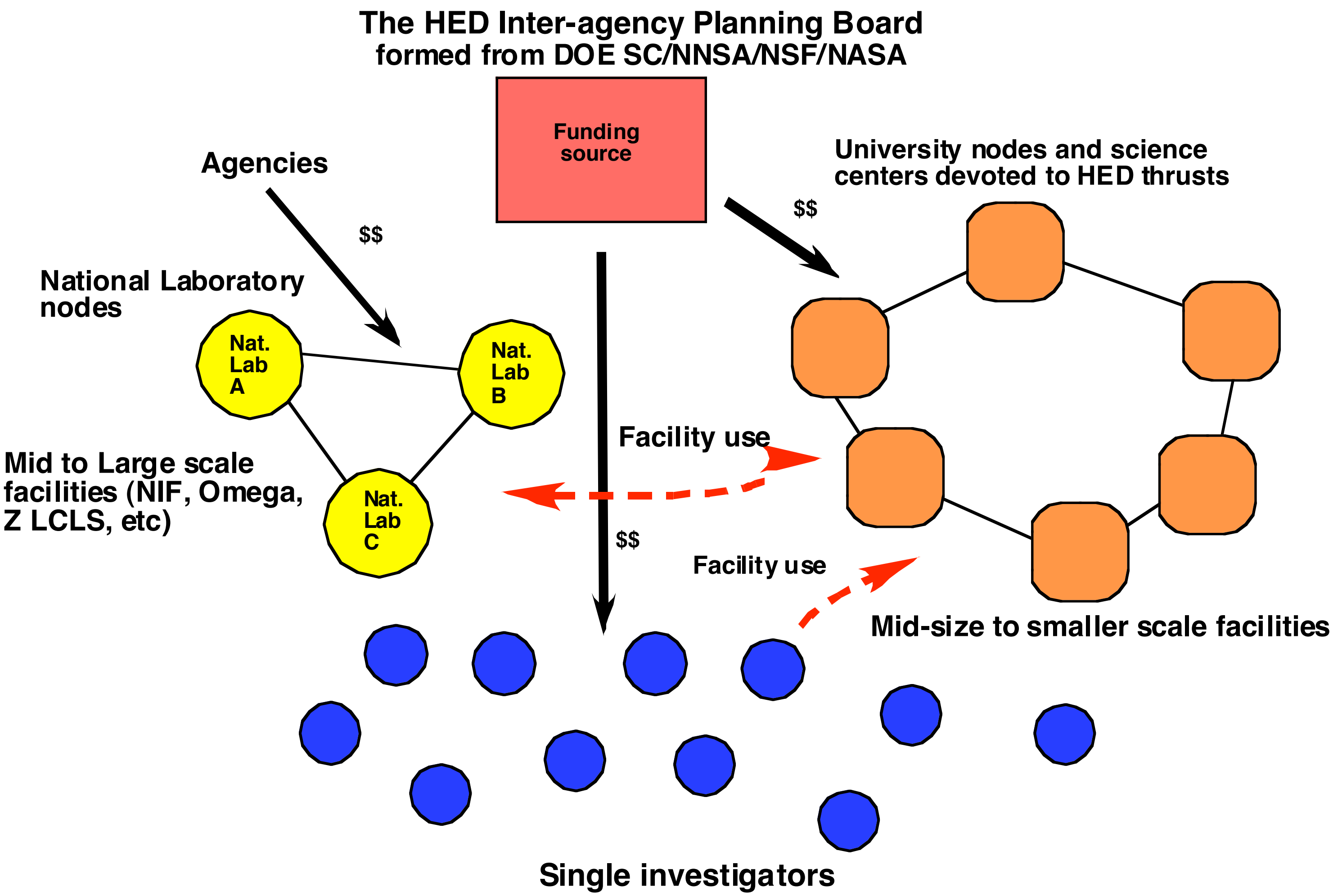
# One effective way to organize the national effort would be to form a national network in UUL science

***network:***

1) Formation of a funded cross agency body (CAB)
2) The CAB would hold nation-wide competition for the formation of network nodes.
3) The network would include three kinds of nodes:
   (a) Facilities at National Labs and existing large scale laboratories.
   (b) Centers at universities.
   (c) Single investigator efforts
4) Single Investigators are a key component. Will have access to the facilities at the network nodes
5) Network will be a dynamic entity with a recurring competition for new and existing nodes. Can also sunset nodes.



# Dick Lee has approved a new HED network to organize this community



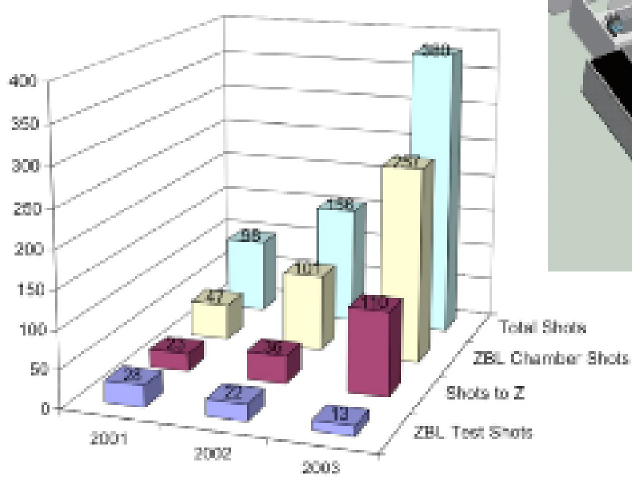
# The nodes of this HED structure will be based on science opportunities

Examples of possible node themes include:

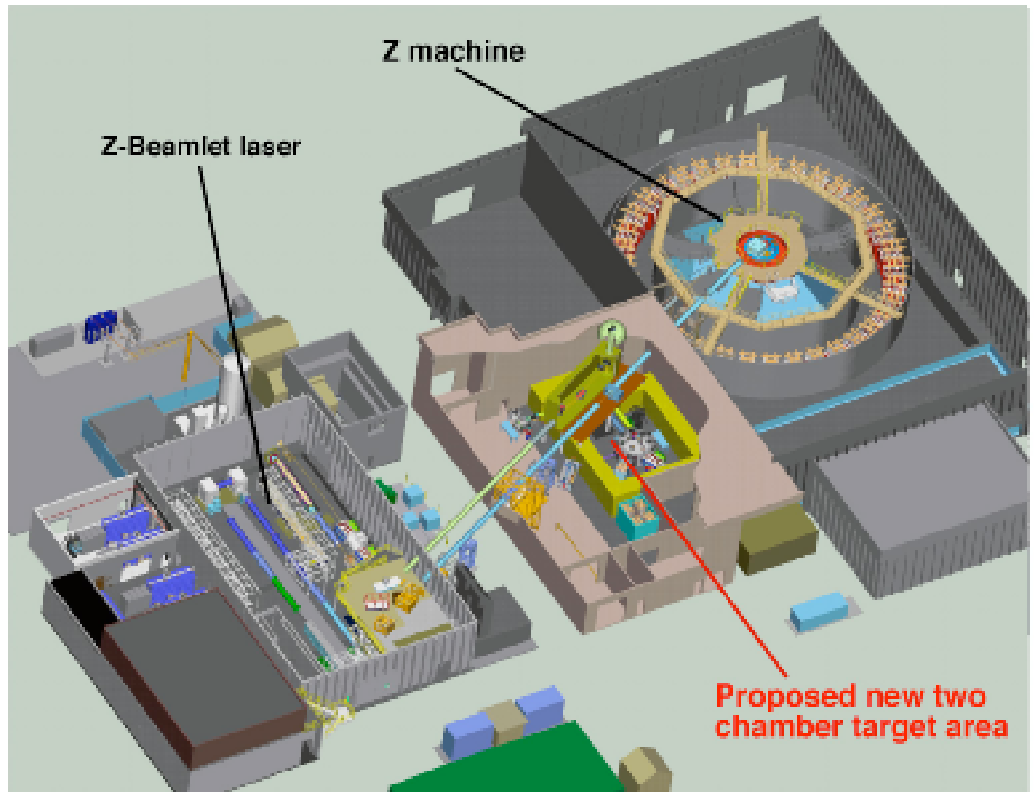
1) Basic high field science
2) Computational high intensity physics
3) High energy density science.
4) Laboratory astrophysics
5) Fast Ignition
6) Hyperfast (attosecond) x-ray source development and applications
7) Structural dynamics
8) Advanced particle acceleration and ultrafast nuclear science
9) Ultrafast nuclear science

# The Sandia Z-BL/PW facility represents an example of a mid-scale NNSA facility potentially ideal for outside use

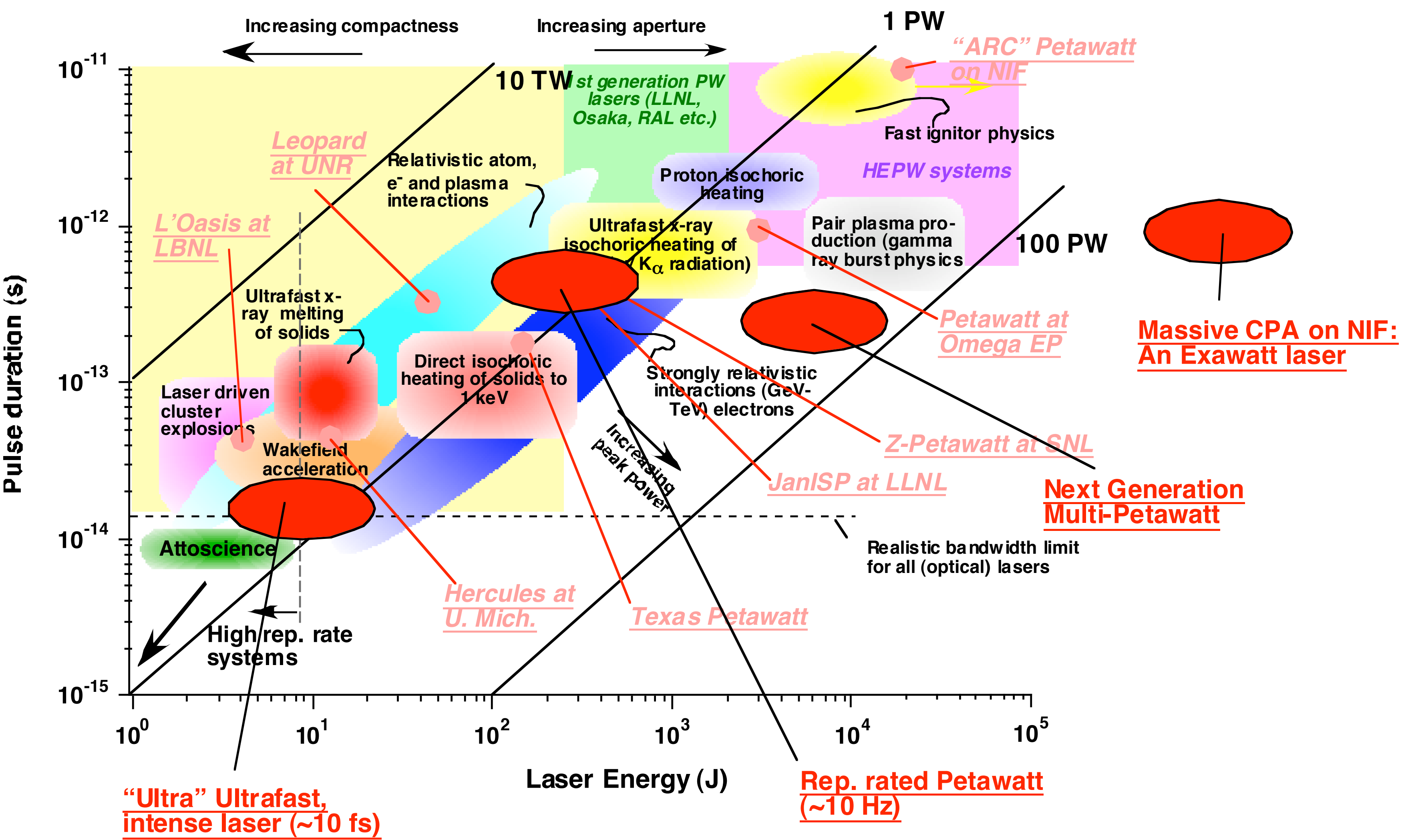
**Summary of Z-Beamlet shots**
**2001 - 2003**



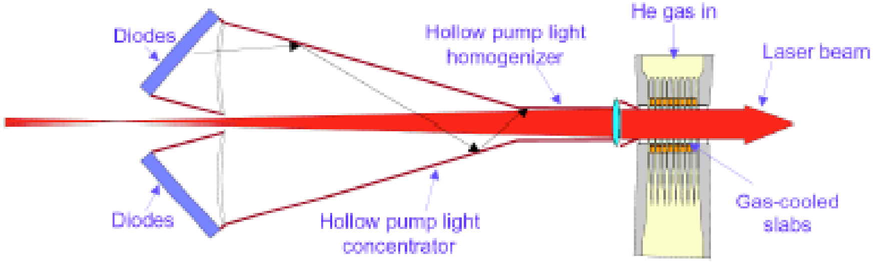

Proposed location of the Sandia Two-Beam Target Area

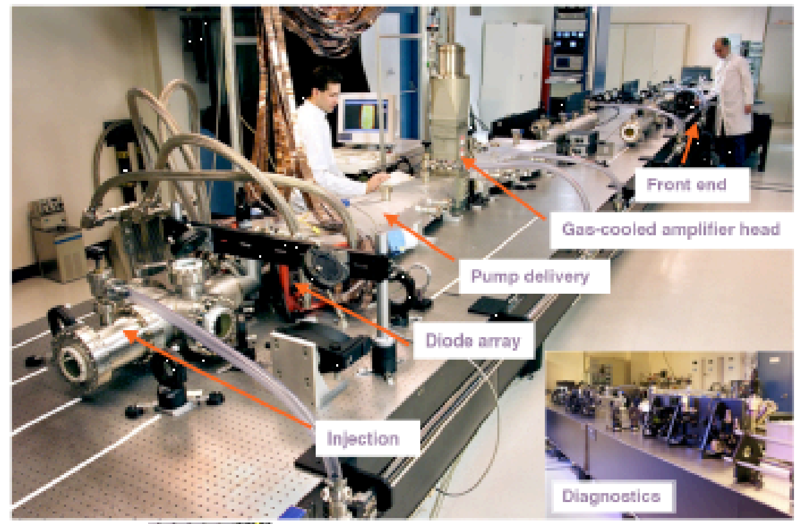


# Are there any missing systems in UUL Phase space?

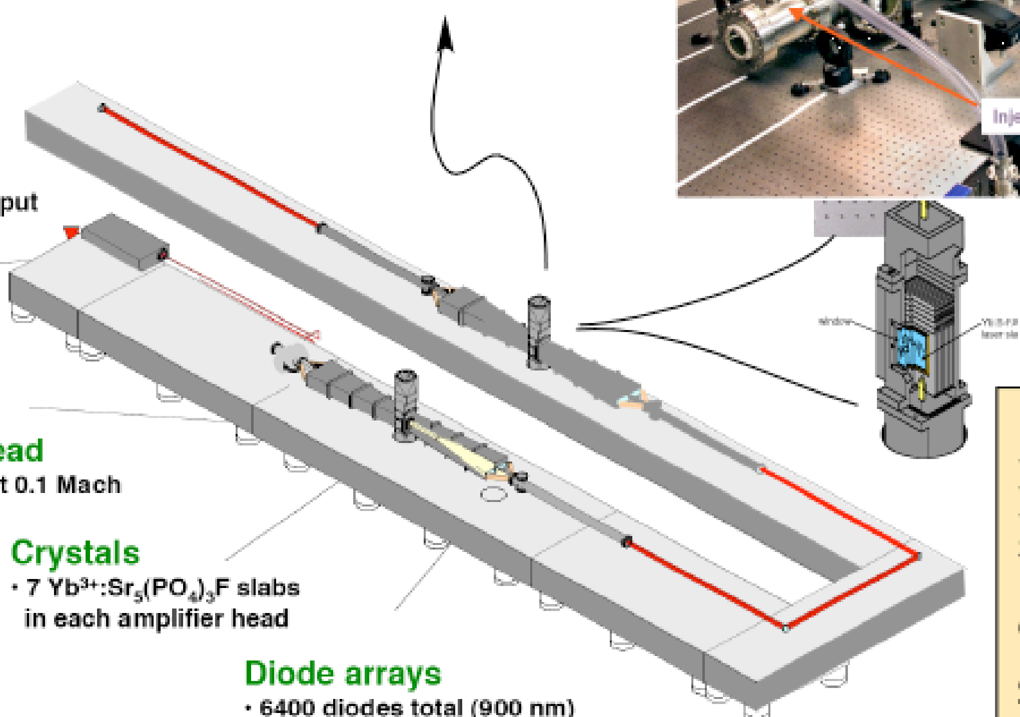


# At LLNL the Mercury laser is being developed to push the technology of high rep. rate, high energy lasers




Output



**Front-end**
- 300 mJ, $M^2$=1.8

**Gas-cooled amplifier head**
- He gas flow at 0.1 Mach

**Crystals**
- 7 $Yb^{3+}$:$Sr_5(PO_4)_3F$ slabs in each amplifier head

**Diode arrays**
- 6400 diodes total (900 nm)
- 640 kW peak power

***Mercury will deliver***

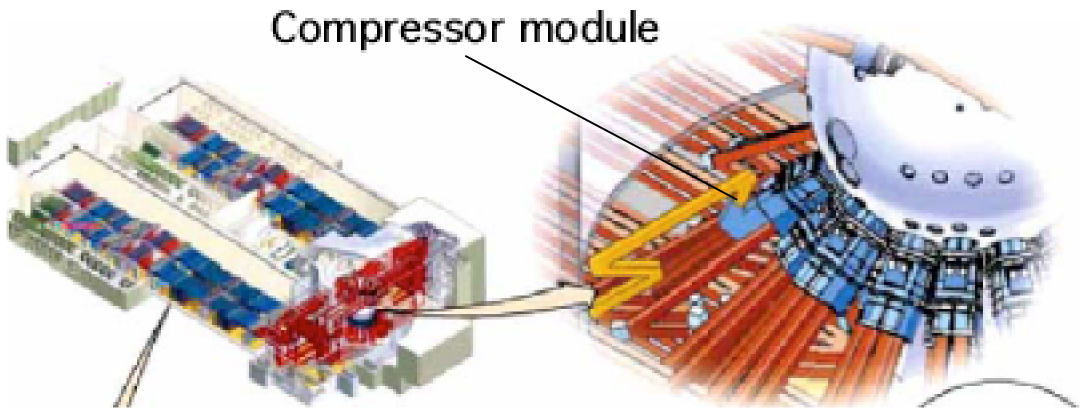
**100 J pulses**
**10 Hz rep. rate**
**1047 nm wavelength**
**2-10 ns pulse**

**CPA can be implemented directly on Mercury or the nanosecond pulses can be doubled and used to pump Ti:sapphire or OPCPA**

*Information taken from a review talk by C. Bibeau*

# Massive implementation of CPA on NIF could allow us to reach the Exawatt threshold ($10^{18}$ W)

## NIF HEPW design




**CPA on one NIF Beam line: 5 kJ @ 0.5 ps = 10 PW**
**will require high damage threshold gratings**

**CPA on half of NIF: 10 PW x 96 beams = 1 EW !!**
**focused intensity $\longrightarrow$ ~$10^{24\text{-}25}$ W/cm$^2$**